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FERAL GOAT ERADICATION ON SAN CLEMENTE ISLAND, CALIFORNIA

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Feral goats (*Capra hircus*) have been reported to negatively affect biota and physical environments of several islands (Coblentz 1978, Daly and Goriup 1987). Such effects included overuse of favored plant species; absence of seedling regeneration of favored plants; replacement of favored plants by nonpreferred plants; initiation and acceleration of erosion; reductions of standing-crop biomass, productivity, biodiversity, and stability; and potential extinction (Coblentz 1990). Protection of insular systems is probably impossible without elimination of feral goats (Vitousek 1988). Endemic biota on San Clemente Island (SCI), California, have been severely degraded by feral goats since 1875 (Johnson 1975); to date, 4 plant, 2 bird, and 1 reptile species endemic to SCI have been listed under the Endangered Species Act of 1973 (U.S. Navy 1979). An additional 24 plant and 5 animal species on SCI have been considered for listing (U.S. Navy 1981:4-34 to 4-39).

Since 1934, SCI has been under the jurisdiction of the U.S. Navy. The Navy's primary objective for SCI was to protect species listed as threatened or endangered; feral goats must be removed to achieve this objective (U.S. Navy

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1981). Approximately 29,000 goats were removed from SCI between 1972 and 1989 (J. K. Larson, U.S. Navy, San Diego, Calif., pers. commun., 1992) during an intensive feral goat eradication program, but a small remnant population remained. Attempts to locate and eradicate SCI goats became increasingly inefficient as the population decreased and survivors become more wary.

The Judas goat technique uses gregarious behavior of radio-collared goats to locate widely distributed remnant herds of feral goats (Taylor and Katahira 1988). With this technique, a goat is fitted with a radio transmitter and released in an area suspected of harboring feral goats. Solitary goats have a strong drive to locate conspecifics (Shackleton and Shank 1984), and they can locate other goats more efficiently than can humans. After a Judas goat joins a feral herd, all goats except the Judas goat are killed. The Judas goat is spared so that it will search out other goats (Taylor and Katahira 1988); this process continues until Judas goats encounter only other Judas goats and eradication is achieved.

In Hawaii Volcanoes National Park (HVNP), remnant feral goat herds were located by relocating Judas goats at 2-month intervals (Taylor and Katahira 1988). We postulated that Judas goats could locate conspecifics in much less than 2 months; less time between locations could expedite eradication and reduce costs.

Our goal was to determine the effectiveness of the Judas goat technique in eradicating the remnant feral goat population on SCI. Our specific objectives were to determine the length of time required by Judas goats to establish contact (initial encounter time) with remnant goats on SCI and to locate conspecifics after previously encountered goats were killed (subsequent encounter time). Additionally, we wanted to determine the duration of association between Judas goats and remnant herds, the area traversed by Judas goats, and the maximum effective search distance Judas goats traveled to find conspecifics.

STUDY AREA

San Clemente Island, California, 109 km west of La Jolla, California, is the southern-most of the 8 Channel Islands. It is 34 km long and 1.6–6.5 km wide. Much of the 148-km^2 island is steep and rocky. The eastern side is an eroded fault-scarp rising to 600 m (Olmsted 1958) with several rugged canyons extending from the highest elevation to sea level. The gently sloping west side has deep (150 m) canyons.

METHODS

The study was conducted from June 1989 through April 1991. Twelve female goats (8 in June 1989 and 4 in April 1990) were captured by net-gun on Santa Catalina Island, California and transported by helicopter to SCI. Females were used because they were more efficient than males at locating and joining remnant goat herds (Taylor and Katahira 1988). Feral goats from Santa Catalina Island were equipped with radio collars (hereafter referred to as Judas goats), held <6 hours, and released into canyons where groups of feral goats were observed during an initial survey of the island or were suspected based on historical data.

Judas goats were located once or twice each day using radio telemetry. The primary purpose of radio telemetry was to obtain general locations of Judas goats because accurate triangulation was impeded by topographic features. Once the general location (within 200 m) was identified, we used auditory and visual cues to obtain a precise location. If goats were not observable, we mimicked goat vocalizations to elicit a response. Goats were observed with a spotting scope or binoculars to aid in identification of individuals by coat color or pattern, horn shape or size, and association with other group members (e.g., juveniles with mothers). These individual identifications helped to identify goats born during the study as well as those killed and those remaining. Identification of all individuals allowed us to estimate the total remnant goat population on SCI.

After release, Judas goats were radio-tracked from the ground to determine initial and subsequent encounter times. An encounter was defined as being within 50 m of ≥ 1 individual and sharing activities such as moving in the same direction over the same period of time.

We recorded individual identity, number per group, duration of associations, and frequency of group changes by Judas goats. Visual observations were used to estimate limits of areas traversed by Judas goats. We defined maximum effective search range as the long axis across the area traversed by each Judas goat.

The initial shooting of remnant herds encountered by Judas goats occurred between 15–18 September 1989. Three Judas goats in 3 adjacent canyons were located using radio telemetry and the remnant goats associated with them were killed. Another Judas goat was hunted exclusively for 4 consecutive days in February 1990 to determine whether, after all associates were killed, a

Judas goat would encounter conspecifics on a daily basis.

An intense eradication effort began February 1990. Shooting from the ground was conducted opportunistically throughout the study and was periodically combined with shooting from a helicopter after April 1990.

As remnant feral goats were eliminated, Judas goats began locating other Judas goats. If a group of 2–3 Judas goats did not locate remnant herds within a 3-week period, 1 or 2 were either recaptured and relocated, or they were killed to encourage survivors to search for and locate remnant herds. This continued until all remnant feral goats were killed on SCI.

Repeated measures analysis (Devore and Peek 1986: 589) was used to test the null hypothesis that subsequent encounter time remained constant as goat density decreased over time. Statistical significance was accepted at $P \leq 0.05$.

RESULTS

Eleven of 12 Judas goats first encountered conspecifics in ≤ 5 days. Mean time to initial encounter was 2.4 days ($n = 11$, SE = 0.4, range = 1–5). Subsequent encounter times averaged 2.2 days ($n = 11$, SE = 0.5). Ten Judas goats located conspecifics a minimum of 16 times each. Two Judas goats had <3 subsequent encounters and were therefore eliminated from the repeated measures analysis. As goat numbers decreased, we did not detect an increase in subsequent encounter times ($n = 10$, $P \geq 0.05$). Eleven Judas goats were with remnant feral goats virtually each time (often daily) we located them during the first 12 months of the study. Only 1 Judas goat failed to contact other goats, perhaps because no goats were within its 3.2-km maximum effective search range. Judas goats continued to locate other goats quickly even when the population totaled <6 goats.

Judas goats associated with 248 other feral goats, and several goats were contacted by >1 Judas goat. Because encounters by each Judas goat were treated independently, the total number of associations was 303. The number of goats encountered by each Judas goat (excluding 1 that encountered none) averaged 27.5 ($n = 11$, SE = 6.2, range = 4–73). Judas goats encountered another Judas goat on 10 separate occasions, and groups of 3 Judas goats occurred twice.

Feral goat herds were relatively ephemeral associations. Mean feral goat group size was 5.0 ($n = 11$, SE = 0.8, range = 2–17), and goats remained in the same group for a mean of 11 days ($n = 11$, SE = 4.2, range = 1–60 days). Once shooting began, duration of associations often decreased because the associate goats were killed. Judas goats traversed an area averaging 4.4 km^2 ($n = 12$, SE = 0.8, range = 0.7–11.2 km^2) on SCI. The effective search range of Judas goats averaged 4.8 km ($n = 12$, SE = 0.4, range = 2.8–7.1 km).

Twenty-eight associates of 3 different Judas goats were killed in adjacent canyons during the initial removal of remnant goats in September 1989. In this preliminary effort, 100% of the goats in 2 of the 3 canyons were killed, and 13% were killed in a third canyon.

A Judas goat that was hunted exclusively for 4 days encountered a new group daily. During this period, 21 associate goats were killed, representing approximately 10% of the total and 100% of the local population at the time.

Based on ages of feral goats killed during the study, we estimated that there were 161 goats on SCI on 20 June 1989, when the study began. During the next 16 months, we recorded 105 births. By April 1991, we had killed 260 feral goats and 3 goats had died from natural causes. The remaining 3 goats on SCI were killed in September 1991, after our study was completed. No other goats were seen between September 1991 and October 1993 even though 16 Judas goats from a separate project remained and over 100 hours was spent locating and relocating Judas goats by foot and helicopter.

DISCUSSION

The Judas goat technique greatly facilitated the successful eradication of feral goats from SCI. On SCI, 263 feral goats were eliminated in 22 months, and the last 3 goats were killed

5 months later. These efforts represent an improvement over the previous 4-year period when standard methods failed to remove a population of ≤500 feral goats (J. K. Larson, U.S. Navy, pers. commun., 1993).

Because we identified individual feral goats, we knew group membership of remnant herds in each area. This knowledge enhanced our hunting efficiency by allowing us to predict the number and location of remaining goats and to assess our progress. Therefore we could use various hunting strategies and take advantage of terrain. For example, in the case of a large herd in broken terrain, we could deploy adequate numbers of shooters to cover all escape routes. We felt that it was important to kill entire remnant herds to eliminate escape and to minimize learned wariness. Knowledge of individual goats and their normal movement patterns contributed considerably to the successful eradication of goats from SCI.

Initial encounter time averaged 2.4 days, but Judas goats may have encountered conspecifics before we observed them. Two Judas goats were released at sites historically known to contain goats, but where no goats had been seen recently; 1 never contacted conspecifics. The lack of change in subsequent encounter times as feral goat numbers decreased may have been influenced by our increased knowledge of areas frequented by Judas goats and by our improved ability to document subsequent encounters of Judas goats with feral goats over time. Furthermore, Judas goats were so proficient at locating other goats that as long as another goat occurred within their maximum effective search range, they usually encountered it within 3 days. As remnant feral goats were eliminated, Judas goats began locating other Judas goats, indicating the effectiveness of the technique.

Areas traversed by Judas goats on SCI generally were comparable to female feral goat home-range sizes in New Zealand (Riney and Caughley 1959), Hawaii (Yocum 1967), Santa Catalina Island (Coblentz 1974), and Australia (O'Brien 1984). Taylor and Katahira (1988) did not report home-range size, but suggested that home-range sizes were "fixed" in HVNP. Similarly, areas traversed by Judas goats on SCI did not change over time and goats did not readily cross wide barriers such as the predominant north-south plateau on SCI.

Our data on the gregarious nature of Judas goats agreed with that of Shackleton and Shank (1984) and further demonstrated that goats quickly sought company of other goats. The Judas goat technique, when employed in a rigorous, intensive manner, was more efficient and faster than previously reported for HVNP (Taylor and Katahira 1988). The technique allowed us to completely eliminate elusive remnant feral goats on SCI.

MANAGEMENT RECOMMENDATIONS

The observation that Judas goats quickly sought conspecifics is important to eradication planning, allowing a large reduction in the 2-month interval used by Taylor and Katahira (1988). For example, inaccessible areas could be visited for relatively longer periods (1–2 weeks) rather than making repeated trips and thereby extending the time available for goats to reproduce.

To minimize the effort required to locate the last few goats in an area and to minimize effort spent documenting successful eradication, it is helpful to have an initial monitoring period when individual feral goats are identified and population size is assessed.

We recommend releasing 1 Judas goat/2 km^2 as an approximate density that would fully saturate most feral goat populations from which home ranges have been reported (Riney and Caughley 1959, Yocum 1967, Coblentz 1974: 53, O'Brien 1984). However, because goats apparently avoided crossing large open areas, it may be necessary to deploy more goats in areas delineated by high ridges, wide plateaus, or deep canyons where discrete populations may reside. Based on initial and subsequent encounter times, we recommend locating Judas goats at 2- to 4-day intervals.

The Judas goat technique likely can be used for any population density, but traditional removal techniques may be more cost effective during the initial eradication stages for dense populations when goats can be easily located (Rice 1991). In 1989, the remnant population on SCI was already too small to assess the point when the Judas goat technique becomes cost effective. Nevertheless, the technique was effective on SCI. The Judas goat technique should have the same potential on other oceanic islands where eradication of goats is necessary to provide long-term preservation of native biota. Therefore, we encourage eradication of feral goats and strongly recommend the Judas goat technique for finding and removing remnant groups of any gregarious species in need of control.

SUMMARY

Feral goat (*Capra hircus*) populations adversely impact native insular biota and physical habitats worldwide. We began studying the effectiveness of the Judas goat technique for eradicating remnant feral goats on San Clemente Island (SCI), California, in June 1989. By September 1991, 266 feral goats had been killed on SCI and no additional goats were known to remain. The average length of time required by radio-collared (Judas) goats to establish initial contact with remnant goats was 2.4 days, and time to subsequent encounters with new goats averaged 2.2 days. Areas traversed by Judas goats and maximum effective search distance averaged 4.4 km^2 and 4.8 km, respectively. Use of the Judas goat technique contributed substantially to feral goat eradication on SCI.

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GRAY WOLF RESPONSE TO REFUGE BOUNDARIES AND ROADS IN ALASKA

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Road density in Minnesota and Wisconsin has been shown to influence wolf (*Canis lupus*) distribution and thus may be used to predict the suitability of areas to sustain breeding populations of wolves. Three studies (Thiel 1985, Jensen et al. 1986, Mech et al. 1988) were in general agreement that wolf packs did not persist where road density exceeded approximately 0.6 km/km^2. Low-density wolf populations may be supported at greater road densities when adjacent areas have either no roads or low road densities (Mech 1989). Management plans to benefit wolves may include reduction of roads and seasonal or permanent gating of roads to reduce human access (Land and Resour. Manage. Plan, Ottawa Natl. For. 1986, State of Minn. For.—Wildl. Hab. Manage. Guidelines, St. Paul, 1988 update).

Although it is generally assumed that road access increases human-caused mortality of wolves (Mech 1989), other factors such as avoidance by wolves of roads used by humans also may contribute to the road-density effect. Wolf response to human habitation and roads closed to human access has not been evaluated. A better understanding of wolf behavior in relation to human presence may help facilitate wolf-human coexistence in areas of proposed development or wolf recovery.

We examined wolf response to road types (highway, secondary road, and gated road) and to human presence at the boundaries of Kenai National Wildlife Refuge (KNWR), Alaska. Our purpose was to better characterize the influence of human settlement on wolf distribution.

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